

Increasing Growth and Yield of Upland Rice by Application of Vesicular Arbuscular Mycorrhizae and Potassium Fertilizer

Dedi Natawijaya

Faculty of Agriculture, Siliwangi University, Jalan Siliwangi No 24 Tasikmalaya 46115, Indonesia,
e-mail: dedinatawijaya@yahoo.com

Received 4 November 2010 / accepted 27 December 2011

ABSTRACT

Field experiment with a split plot design has been carried out in order to assess the growth characteristics and yields, and effectiveness of MVA upland rice which were given potassium fertilizer in two growing seasons. MVA inoculation consisted of three treatments (without MVA, *Glomus* sp. and *Gigaspora* sp.) while potassium fertilizer consisted of five levels (0, 12.5, 25, 37.5, and 50 kg ha⁻¹ K). The results showed that plant growth variable which was inoculated by MVA at any levels of K fertilizer was higher in the dry season than that in the wet season, whereas the opposite occurred for net assimilation rate. Potassium content of leaf tissue, shoot/root ratio, and grain weight per hill was determined and mutually dependent on genus MVA, dosages of K fertilizer, and growing season. Harvest index and grain dry weight per hill were influenced by the growing season and the genus MVA but the effect did not depend on each other. At all dosages of K fertilizer and any MVA genera, *Gigaspora* sp. inoculation was better than that of *Glomus* sp. Dry weight of grains per hill was affected by the contribution of grain content per hill, weight of 1000 grains and number of productive seedlings per hill. The optimum dosage of K fertilizer in the dry season was 32.4 kg ha⁻¹ K with grain yield 3.12 Mg ha⁻¹ for inoculation of *Gigaspora* sp., whereas the optimum dosage in the wet season was 34.2 kg ha⁻¹ K for the treatment *Glomus* sp. inoculation with *Gigaspora* sp. in the wet season did not reach dosages of optimum K fertilizer.

Keywords: Harvest index, MVA, potassium fertilizer, upland rice

INTRODUCTION

The availability of rice in sufficient quantities can improve the economic stability. National-scale shortage of rice has implications on the increase of import of rice. The contribution of upland rice in the procurement of the national rice production is almost no change over the last few years. The contribution of upland rice in 1995 was approximately 5.9% with the total area of 14.5% (BPTP 1997). In 1996 and 1997 upland rice contribution on the national rice production was 6% with the average yield 2.21 Mg ha⁻¹. Though the yield per unit area of upland rice increased, the national production tended to decline over the last few years.

The management of potential of dry land for intensive upland rice cultivation provides an opportunity to improve upland rice contributions to the national rice production. Efforts to increase the rice production should be supported with research and development to find effective technology that

can be widely used by farmers. The important yield limiting factors are water stress, mineral stress, diseases, insects and weeds. To improve and/or stabilize yield, these yield limiting factors should be alleviated. An effort to improve upland rice production which relatively cheap is by exploiting the existing potential bio-fertilizer in the local area, for example by exploiting the ability of microbes that can provide a natural fertilizer such as Mycorrhizae.

Mycorrhizae are fungi that associate with plant roots. Two types of mycorrhizae *i.e.* those that lives on the outside of the root (ectomycorrhizae) and those which hypha incorporated into plant root tissue (endomycorrhizae). Endomycorrhizae is known as MVA (vesicle-arbuscular mycorrhizae). MVA may establish a special organ called arbuscular and vesicles, each of which is an organ that functions in nutrient transfer and the storage of food reserves. VAM inoculation can increase yield of agricultural crops, because not only it can assist in expanding the uptake of nutrients, but also it can change the nutrient which is not available into available nutrient for plants (Musfal 2010) and can change the morphology of the roots (Setiadi 2003).

Mycorrhizae-beared plants are usually more resistant to drought (Ruiz-Lozan *et al.* 1995; Boomsma and Vyn 2008) because mycorrhizae will assist in the absorption of water during the plant roots can no longer absorb water and can withstand the cortex from the negative effects of drought. If the period of water shortage has been exceeded, the plant will quickly return to normal condition as fungi absorb water contained in soil pores (Allen and Allen 1992; Indaryanto *et al.* 1997).

Upland rice requires elements of K in plant tissue; K plays a major role in plant metabolism. Soil contains very low of potassium (K-HCl 25% < 8.3 mg K per 100 g soil) need K fertilizer as many as 150 to 200 kg ha⁻¹ of KCl to prevent the plants from K-deficiency (Musfal 2008).

The role of potassium in increasing plants resistance to drought stress has been reported by Abdullah (1995) in which the application of potassium 25 to 50 kg ha⁻¹ of K caused the crop more resistant to drought stress that occurred in the early and last stage of the vegetative phase. Therefore, appropriate potassium fertilization, both dosage and time of application is very important, especially in upland rice cultivation system, which lands are relatively poor of nutrient. In plant contains sufficient amount of potassium, more photosynthates transported from leaf to root system due to the increasing of enzyme activity and solubility of simple sugar and its distribution to the other parts of the plants (Douds and Millner 1999).

The relationship between soil environment and climate, the MVA genera, and the amount of fertilizer affect plant growth. Thus, inoculation with different VAM genera and potassium fertilizer application at variation dosage on upland rice crops will lead to interactive effects as expressed in the growth characteristics, yield components, and yield and as well effectiveness of MVA, both in the dry and wet seasons.

The objectives were to study the characteristics of growth, yield components and yield, as well as effectiveness of mycorrhizae in upland rice applied with K fertilizer at two growing seasons; the interaction between K-fertilizer, mycorrhizae, and growing season; and to obtain the optimum dosage of K-fertilizer at each growing season and each mycorrhizae inoculants.

MATERIALS AND METHODS

Study Site and Materials

The research was carried out twice, in the dry and wet seasons located in Kawalu District,

Tasikmalaya, West Java. The materials used in the research were: (1) seed of upland rice cultivar Way Rarem as plant material, (2) Urea (45% N), TSP (46% P₂O₅), and the sheep manure as basal fertilizer, and KCl (50% K₂O) as the treatment factor, (3) VAM inoculants consisting of propagules of *Glomus* sp. and *Gigaspora* sp.

Experimental Treatments and Variable

The research were arranged by split plot design in a randomized completely block design and the treatment combinations was replicated three times. The main plot was potassium fertilizer that consisted of five levels, namely 0, 12.5, 25, 37.5 and 50 kg K ha⁻¹, and subplot was mycorrhizal inoculation that consisted of three levels, *i.e.* without VAM, *Glomus* sp., and *Gigaspora* sp. Inoculant that was used was in the form of soil with roots (propagules) from propagated pot with a dosage of 50 g of spore per hole.

The main response-variable was potassium content in leaf tissue, harvest index, number of filled grain per hill, grain dry weight, number of productive tiller per hill, root colonization and number of spore of VAM. Ratio of shoot/root was also calculated.

VAM Fungi Colonization and Spores Number

At the end of the experiment, the root colonization by VAM fungi was determined. Root samples were rinsed with tap water and cut into 1-cm pieces, cleared with 10% KOH, stained with 0.05% trypan blue in lactophenol as described by Phillips and Hayman (1970). The root segments were mounted on slides and examined with a compound microscope. The percentage of colonized root were calculated.

VAM spores from the soil samples (25 g) were extracted by wet sieving, decanting and followed by sucrose density gradient centrifugation (Daniels and Skipper 1982). Spore, spore clusters and sporocarps obtained from all the sieves (400, 250, 150 and 40 µm mesh size) were observed by using a stereo-zoom microscope.

Statistical Analysis

All data (at both seasons) were statistically analyzed by analysis of variance (ANOVA) after the normality (Gomes and Gomes, 1984) using the SPSS software package (SPSS 10 for Windows). Duncan's multiple-range test was performed at $p = 0.05$ on each of the significant variables measured.

Table 1. Potassium content in leaf tissue of upland rice at different dosages of potassium and VAM inoculation in two growing seasons.

Gowing Season	Potassium Fertilizer (kg ha ⁻¹)	Mycorrhizae		
		Without Mycorrhizae	<i>Glomus</i> sp.	<i>Gigaspora</i> sp.
..... % K				
Dry Season	0.0	2.32 ab (A)	2.35 b (B)	2.63 c (B)
	12.5	2.52 bc (B)	2.29 ab (B)	2.26 ab (A)
	25.0	2.56 c (B)	2.29 ab (A)	2.44 b (A)
	37.5	2.34 b (A)	2.12 a (A)	2.17 a (A)
	50.0	2.29 a (A)	2.39 b (A)	2.16 a (A)
	0.0	2.26 p (P)	2.19 p (P)	2.26 p (P)
	12.5	2.18 p (P)	2.05 p (P)	2.12 p (P)
	25.0	2.38 p (P)	2.36 pq (P)	2.69 q (Q)
	37.5	2.38 p (P)	2.35 pq (P)	2.62 q (Q)
	50.0	2.26 p (P)	2.43 q (Q)	2.45 pq (Q)

Note: Means followed by the same small letter in the same column and capital letter with parenthesis in the same row were not significantly different according to Duncan Multiple Range test at 95% confidence level.

RESULTS AND DISCUSSION

Potassium Content

The effect of VAM inoculation on leaf potassium content showed that the dosages between 0-25 kg ha⁻¹ K with *Glomus* sp. and *Gigaspora* sp. was effective enough in the dry season, whereas for the second wet season genus MVA was effective in higher dosages, i.e. between 25-50 kg ha⁻¹ K (Table 1).

Interaction effects occurred between planting seasons, K fertilizer, and mycorrhizae in influencing the ratio of shoot and root (S/R). *Glomus* sp. and *Gigaspora* sp. meaningful impact on the dosage 37.5 kg ha⁻¹ K. The results showed that the effect of average value of all dosages K fertilizer on S/R ratio and all genus MVA during the dry season which was 5.87 higher than the S/R ratio during the wet season was 4.53 (data not shown).

Harvest Index

In general, the highest harvest index was achieved in the dry season, regardless of the given

dosages of K fertilizer, whereas the second MVA each genus *Gigaspora* sp. season was higher than with *Glomus* sp. *Gigaspora* sp. thus was more effective than *Glomus* sp. variables in influencing the harvest index. Harvest index in dry season was 0.47 while in the wet season was 0.40.

Yield Component

The number of filled grain per hill was only affected by differences in growing season, and in the dry season was higher than in the wet season. This may be caused by solar radiation during the dry season which was higher than in the wet season so it affect the accumulation of photosynthate. Similarly the percentage of empty grain parameters per hill was only influenced by the planting season, which in the dry season was higher than in the wet season. The higher the percentage of empty grain, the more the interference that may cause grain rice did not well developed. This can be caused by environmental factors such as higher temperatures that can cause pollen to abortion, as well as physical disorders such environments by pests and diseases that resulted in the empty grain.

Table 2. Harvest index (HI) of upland rice at different dosages of potassium fertilizer and VAM inoculation in two growing seasons.

Growing Season	Potassium Fertilizer (kg ha ⁻¹)	Mycorrhizae		
		Without Mycorrhizae	<i>Glomus</i> sp.	<i>Gigaspora</i>
..... Harvest Index				
Dry Season	0.0	0.48	0.46	0.49
	12.5	0.47	0.46	0.53
	25.0	0.47	0.42	0.52
	37.5	0.44	0.46	0.46
	50.0	0.51	0.48	0.49
Average		0.47 b (AB)	0.45 b (A)	0.49 b (B)
Wet Season	0.0	0.40	0.41	0.42
	12.5	0.41	0.37	0.36
	25.0	0.39	0.43	0.47
	37.5	0.44	0.39	0.42
	50.0	0.39	0.39	0.44
Average		0.40 a (AB)	0.39 a (A)	0.42 a (B)

Note: Means followed by the same small letter in the same column and capital letter with parenthesis in the same row were not significantly different according to Duncan Multiple Range test at 95% confidence level.

Table 3. Number of filled grain per hill of upland rice at different dosages of potassium fertilizer and inoculation of MVA in two growing seasons.

Growing Season	Potassium Fertilizer (kg ha ⁻¹)	Mycorrhizae			Average
		Without Mycorrhizae	<i>Glomus</i> sp.	<i>Gigaspora</i> sp.	
..... Filled grain number hill ⁻¹					
Dry Season	0.0	1122.33	1019.66	1115.00	1165.93 b
	12.5	1007.66	1114.33	1672.00	
	25.0	1281.00	985.66	1348.66	
	37.5	1032.33	1153.33	1106.33	
	50.0	1261.33	1158.66	1110.66	
Wet Season	0.0	1065.00	936.33	988.33	971.39 a
	12.5	1033.33	858.66	890.00	
	25.0	876.66	1000.66	1226.66	
	37.5	848.33	1136.66	996.66	
	50.0	770.00	866.66	1050.00	

Note: Means followed by the same small letter in the same column were not significantly different according to Duncan Multiple Range test at 95% confidence level.

The main yield component which determines the yield was the number of filled grain per hill, both in the dry season and wet season. The optimum dosage of K-fertilizer at the dry season for without MVA, *Glomus* sp., and *Gigaspora* sp. were 4.3,

9.0, and 32.4 kg ha⁻¹, respectively. While at the wet season the optimum dosage for without MVA and *Glomus* sp. were 16.7 and 34.2 kg ha⁻¹, respectively. Inoculation with *Gigaspora* sp. did not reach the optimum dosage.

Table 4. Dry weight of grain per hill of upland rice at different dosages of potassium fertilizer and VAM inoculation in two growing seasons.

Growing Season	Potassium Fertilizer (kg ha ⁻¹)	Mycorrhizae (M)		
		Without Mycorrhizae	<i>Glomus</i> sp.	<i>Gigaspora</i> sp.
..... Dry weight hill ⁻¹ (g)				
Dry Season	0.0	29.50	25.00	28.33
	12.5	25.50	26.00	43.50
	25.0	33.16	25.16	37.33
	37.5	25.00	27.50	28.83
	50.0	33.83	29.16	29.66
Average		29.39 b (AB)	26.56 b (A)	33.53 b (B)
Wet Season	0.0	29.33	21.33	28.50
	12.5	24.16	17.83	18.66
	25.0	21.00	24.50	39.00
	37.5	20.33	26.00	22.50
	50.0	17.00	20.00	24.66
Average		22.36 a (A)	21.93 a (A)	26.66 a (B)

Note: Means followed by the same small letter in the same column and capital letter with parenthesis in the same row were not significantly different according to Duncan Multiple Range test at 95% confidence level.

The effect of yield components on the yield was shown with the path coefficients that directly affect the grain yield. It could be concluded that both in the dry and wet seasons, the component that determined the yield was the number of filled grain per hill. The percentage contribution of each component on yield in each growing season was different. The order of contribution, the largest to the smallest, of the yield component in the dry season respectively was the number of filled grain per hill (96%), weight of 1,000 dry grain (61%), and the number of productive tillers per hill (56%). In the wet season, with the same order was the number of filled grain per hill (89%), number of productive tillers per hill (84%), and weight of 1,000 g dry grain (83%), respectively.

Basically, the larger grain yield is determined by the optimum conditions of plant growth phase as

the period of flowering, seed filling, maturation and ripening. It is related with the total leaf area at flowering phase which affect the availability of photosynthate at the panicle (Kabirun 2002). In addition, environmental conditions such as intensity of solar radiation, air temperature, root zone temperature, difference between day and night temperature and the amount of water and nutrients in the soil can be a decisive indicator of the amount of crop yield per unit area (Matsuo and Hoshikawa 1993).

The difference of environmental factors and its fluctuation affect physiological processes that occur on each yield component so as to give different grain yield in the dry and wet seasons. For comparison, the experimental results of BPTP (1997) with cultivars Way Rarem and IR 53 236 in the wet season 1996, that showed that the largest to the

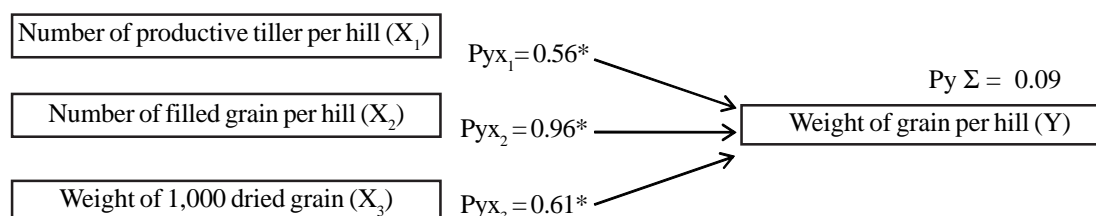


Figure 1. Path analysis between yield components and grain yield per hill of upland rice in the dry season.

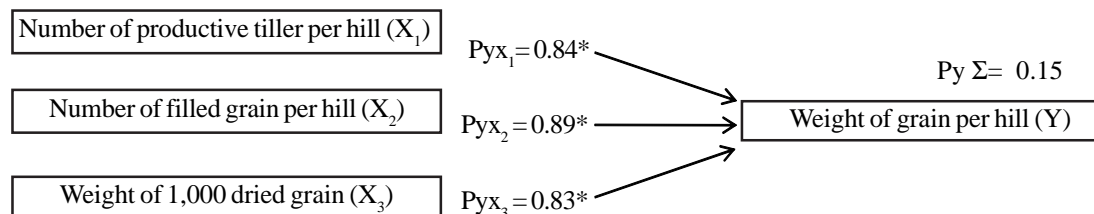


Figure 2. Path analysis between yield components and grain yield per hill of upland rice in the wet season.

smallest contribution in was the number of filled grain per hill, weight of 1,000 dried grain, and number of productive tillers per hill.

Plant growth rate and net assimilation rate showed different patterns between different dosage, however, in general the value of these parameters increased although did not show significant effects among the MVA genera

Root Colonization and Number of Spores

The degree of root colonization and number of spores per gram of soil was only affected by the MVA genera. In general, the inoculation of *Gigaspora* sp. was better than those of *Glomus* sp. The colonization existed before 40 days after planting, and it increased until the end of the measurement, though with the different maximum point. The treatment without VAM showed low degree of colonization, whereas the inoculation with *Gigaspora* sp. showed the highest degree of colonization (Table 6).

The degree of colonization was much influenced by host plant species and plant age (Varma 1995). For examples, the degree of 10 weeks colonization were 79% (barley), 82% (corn), 79% (potato), and 82% (onions). While the types of VAM investigated by Werner (1992) showed that inoculation of *Glomus fasciculatum* on *Leucaena leucocephala* plants reached 88% at age 63 days, while *Gigaspora* sp. achieve the degree of colonization of 80% in 3 weeks.

The number of spores increased with the age of the plant (Table 8). At 30 days after planting the spore was formed and the number increased until the end of measurement at 60 days after planting. Even in the plant without mycorrhizae the number of spore tended to increase, it was due to the improvement of micro-ecosystem through the application of organic and inorganic fertilizer, land tillage, which induced the existed mycorrhizae to grow.

Table 5. Degree of roots colonization of upland rice at different dosages of potassium fertilizer and inoculation of MVA in two growing seasons.

Growing seasons	Potassium Fertilizer (kg ha ⁻¹)	Micorrhizae		
		Without Mycorrhizae	<i>Glomus</i> sp.	<i>Gigaspora</i> sp.
	%		
Dry season	0.0	55.00	55.00	70.67
	12.5	55.67	59.33	59.00
	25.0	56.67	63.67	64.67
	37.5	57.67	61.67	69.33
	50.0	57.00	49.00	74.00
Wet season	0.0	47.33	60.67	70.00
	12.5	50.33	63.67	64.33
	25.0	56.67	58.00	51.33
	37.5	50.67	59.00	68.00
	50.0	54.67	65.33	61.00
Average		54.17	59.53	65.23
		(A)	(B)	(C)

Note: Means followed by the same capital letter with parenthesis in the same row were not significantly different according to Duncan Multiple Range test at 95% confidence level.

Table 6. Number of spores of upland rice soil at different dosages of potassium fertilizer and inoculation of VAM in two growing seasons.

Growing seasons	Potassium Fertilizer (kg ha ⁻¹)	Mycorrhizae		
		Without Mycorrhizae	<i>Glomus</i> sp.	<i>Gigaspora</i> sp.
	 Spores number g ⁻¹ soil		
Dry season	0.0	12.00	12.67	15.33
	12.5	10.33	12.67	16.00
	25.0	11.33	13.67	14.67
	37.5	14.67	14.00	12.67
	50.0	13.33	15.67	16.33
Wet season	0.0	10.67	16.00	17.00
	12.5	11.33	15.67	15.67
	25.0	12.33	15.33	13.33
	37.5	11.00	13.33	13.00
	50.0	13.33	13.33	13.67
Average		12.03	14.23	14.76
		(A)	(B)	(B)

Note: Means followed by the same capital letter with parenthesis in the same row were not significantly different according to Duncan Multiple Range test at 95% confidence level.

CONCLUSIONS

Based on the research results, it was concluded that the growth and yield characteristics at all levels of K fertilizer in the dry season was higher than that in the wet season. There was interaction effect of K fertilizers and mycorrhiza on the leave-K content, shoot/root ratio, weight of grain per plot. Whereas, the growing period and VAM genera affected the harvest index and weight of dry grain per hill although did not show interaction effect.

The optimum dosage of K fertilizer in the dry season was 32.4 kg ha⁻¹ K with the grain yield 3.12 Mg ha⁻¹ and inoculated with *Gigaspora* sp. While the optimum dosage of K fertilizer in the wet season was 34.2 kg ha⁻¹ K with the yield 3.21 Mg ha⁻¹ and inoculated with *Glomus* sp.

REFERENCES

- Abdullah S. 1995. Pengaruh cekaman kekeringan pada tiga tingkat pemupukan terhadap kadar hara dan hasil padi gogo di tanah masam. Risalah Seminar BPTP Sukarami VIII: 25-34 (in Indonesian).
- Allen MF and EB Allen. 1992. Development of mycorrhizal patches in a successional arid ecosystem. In: DJ Read, DL Lewis, AH Fitter and IJ Alexander (eds). *Mycorrhizas in Ecosystems*. CAB International. Wallingford, UK, Pp 164-170.
- Boomsma CR and TJ Vyn. 2008. Maize drought tolerance: Potential improvements through arbuscular mycorrhizal symbiosis?. *Field Crop Res* 108: 14-31.
- BPTP [Balai Pengkajian Teknologi Pertanian]. 1997. Laporan tahunan 95/96. BPTP Sukarami, Solok (in Indonesian).
- Daniels BA and HD Skipper. 1982. Methods for recovery and quantitative estimation of propagules from soil. In: Schenck NC (ed). *Methods and principles of mycological research*. The American Phytological Society, St. Paul, MN, pp. 29-35.
- Douds DD and PD Millner. 1999. Biodiversity arbuscular mycorrhizal fungi in agroecosystems. *Agr Ecosyst Environ* 74: 77-93.
- Gomez KA and AA Gomez. 1984. *Statistical Procedures for Agricultural Research*. A Wiley-Interscience Publication, New York.
- Indaryanto BS, R Soedharoedjian, Tohari and Soeprapto. 1997. Usaha peningkatan hasil padi gogo melalui perlakuan pembenah tanah polyacrylamide, polyvinyl alkohol dan inokulasi MVA. Makalah Seminar Nasional Pemberdayaan Lahan Kering untuk Budidaya Pertanian Berwawasan Lingkungan Menyongsong Era Globalisasi, Purwokerto, 27 Pebruari 1997 (in Indonesian).
- Kabirun S. 2002. Tanggapan Padi Gogo Terhadap Inokulasi Jamur Mikoriza Arbuskula dan Pemupukan Fosfat di Entisol. *J Ilmu Tanah Lingk* 3(2): 40-56.
- Matsuo T and K Hoshikawa. 1993. Science of the rice plant. *Morphology* 1: 379-380.
- Musfal. 2008. Efektivitas Cendawan Mikoriza Arbuskula (CMA) terhadap Pemberian Pupuk Spesifik Lokasi Tanaman Jagung pada Tanah Inceptisol. [Thesis] Universitas Sumatra Utara. 79 p.

- Musfal. 2010. Potensi cendawan mikoriza arbuskula untuk meningkatkan hasil tanaman jagung. *J Litbang Pert* 29 (4): 154-158 (in Indonesian).
- Phillips J and D Hayman. 1970. Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. *Trans Br Mycol Soc* 55: 158-161.
- Ruiz-Lozano JM, R Azcon and M Gomez. 1995. Effects of Arbuscular-Mycorrhizal *Glomus* species on drought tolerance: physiological and nutritional plant responses. *Appl Environ Microbiol* 61 (2): 456-460.
- Setiadi Y. 2003. *Arbuscular Mycorrhizal Inoculum Production*. Abstrak Seminar dan Pameran Teknologi Produksi dan Pemanfaatan Inokulan Endo-Ektomikoriza untuk Pertanian, Perkebunan dan Kehutanan. 16 September 2003. Bandung pp 10 (in Indonesian).
- Varma A. 1995. Ecophysiology and application of arbuscular mycorrhizal fungi in arid soils. In: A Varma and B Hock (eds). *Mycorrhiza – Structure, function, molecular biology and biotechnology*. Springer-Verlag, Berlin, pp. 561-592.
- Werner D. 1992. *Symbiosis of Plant and Microbe*. Chapman & Hall, Inc, London, 389 p.